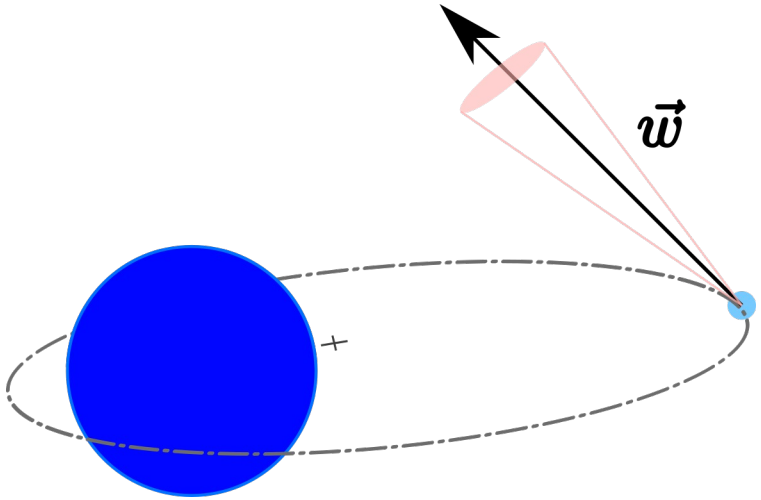
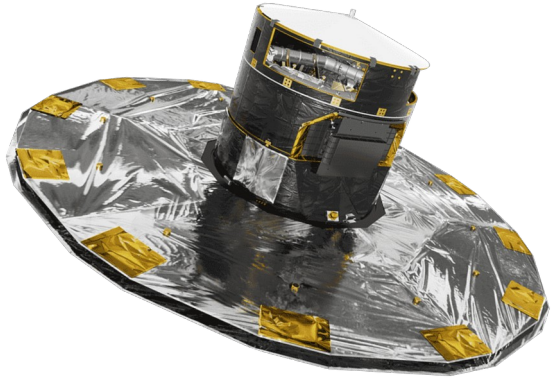
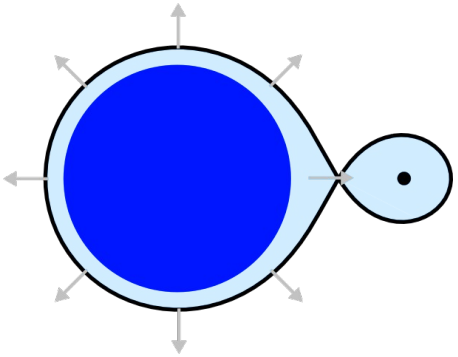
Constraints to neutron star kicks in High-Mass X-ray binaries with Gaia EDR3



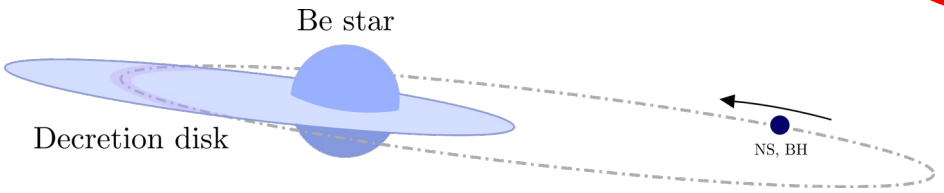


F. Fortin, F. Garcia, S. Chaty, E. Chassande-Mottin, A. Simaz-Bunzel, A&A subm.

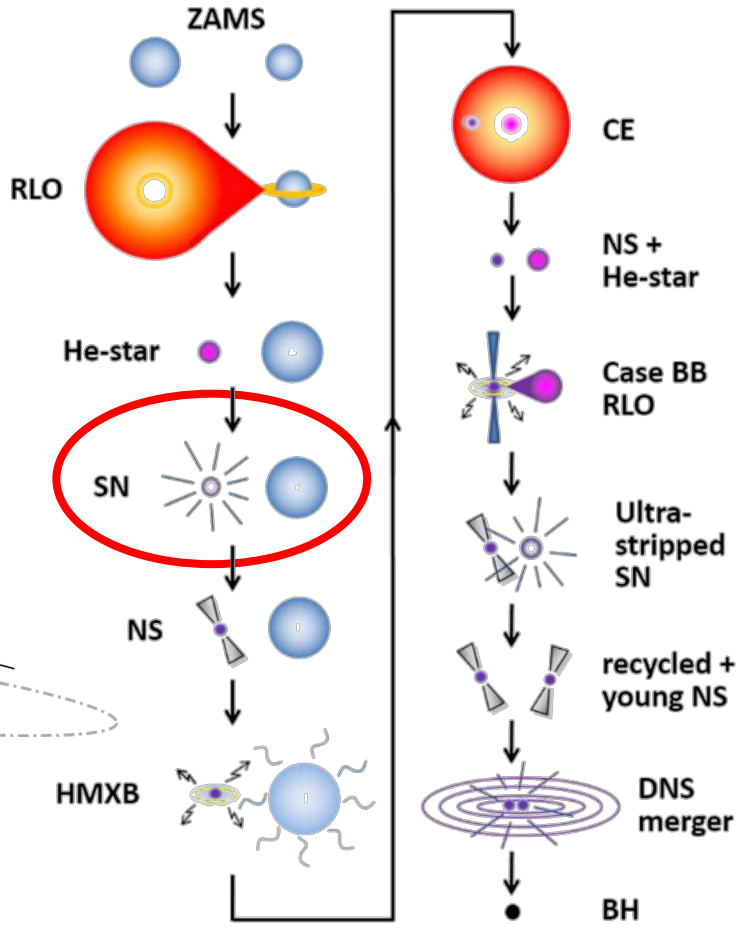
Evolution of High-Mass X-ray binaries



Wind Accretion



Decretion



Tauris+2017

Supernova:

- Blaauw kick

- Asymetry

Survival rate ?

Impact on orbit ?

Natal kicks – State of the art

→ Analytical solution of its impact on orbital parameters in binaries (Kalogera 1996)

→ Cir X-1 velocity & orbit explained by massive natal kick of ~500 km/s (Tauris+1999)

→ Black Hole X-ray binary with high runaway velocity (Mirabel+2002)

→ Isolated pulars: preferential direction of the kick wrt spin ? (Ng & Romani 2013)

→ Natal kick derived on an HMXB with the Australian LBA radio interferometer (Miller-Jones+2018)

→ Radio interferometry + Gaia DR2  to derive kick on 16 BH X-ray binaries (Atri+2019)

Kicks are still misunderstood, most studies tackle a single source in the case of binaries.

→ Need for observational constraints on a population of binaries.

What kick-started the project

Initial PI: Federico Garcia (LabEx UnivEarthS "Bin2Grav" interface project)

→ 2nd data release from Gaia in 2018: sky position + proper motion + parallax

→ Census of X-ray binaries from the Milky Way (Ongoing personal project since ~2017)

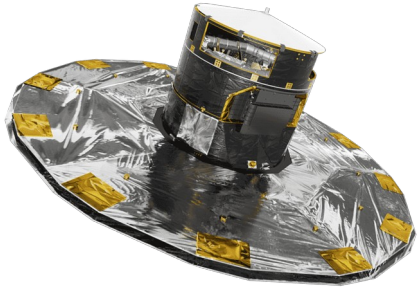
Opportunity to valorize very recent Gaia data:

i) find which HMXBs have been surveyed by Gaia

ii) retrieve their observed position (3D) and velocity (2D) from the data release

iii) infer the kick velocity imparted on each system

iv) any difference within subtypes of HMXB (Be, supergiant...) ?



→ In the meantime, 3rd data release (Dec. 2020)

Building the list of HMXBs

What we need: up-to-date coordinates of HMXBs + all the parameters we can get !

What was already done:

- cross-match between old HMXB catalogue (Liu+2006) with current INTEGRAL sources (Bird+2016)
- cross-match with Simbad (Centre de Données astronomiques de Strasbourg)

What needed to be updated:

- some candidate HMXBs in previous catalogues are now confirmed/discarded
- retrieve exact references for spectral type, mass, period, eccentricity
- find if any radial velocity study was performed

Building the list of HMXBs

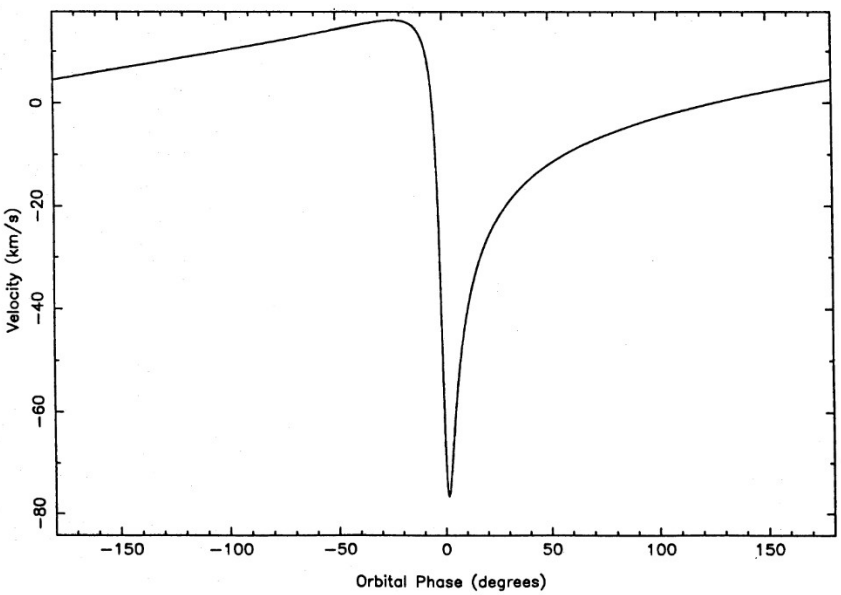
Example: PSR B1259-63

Radial velocity followup of the Oe companion star

→ Curve is presented but no value of the systemic velocity is given in the paper !

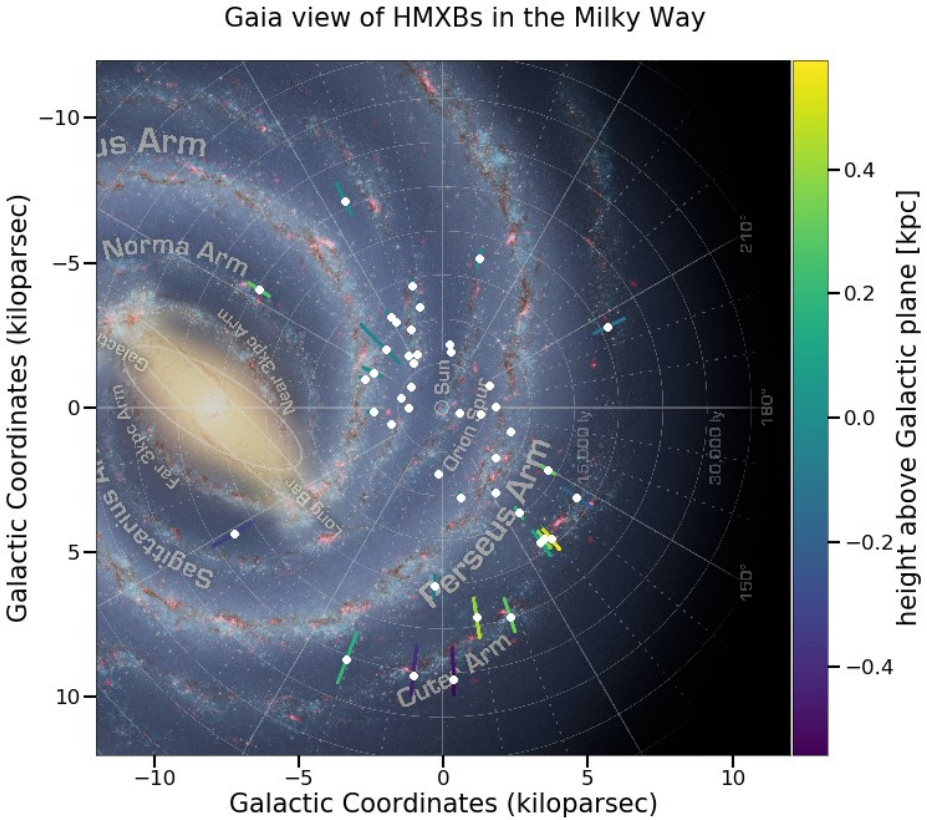
→ WebPlotDigitizer: we retrieved the data from the plot and fitted the systemic velocity

→ Do that for 130 HMXBs in the Galaxy.



Radial velocity of PSR B1259-63 (Johnston+1994)

Gaia counterparts to HMXBs



Fortin et al. A&A subm.

- Position compatible with Spiral Arms (Coleiro & Chaty 2013)
- Galactic warp (Romero-Gomez+2019)

→ **Peculiar velocity:**

Proper motion – Galactic orbital motion

Parallax is the limiting observable:

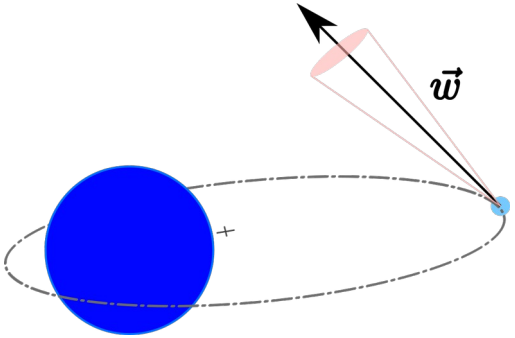
44 HMXBs meet the quality criteria

(SNR & astrometric excess noise)

Deriving kicks

Analytical equation linking pre-SN to post-SN orbital parameters (Kalogera 1996), assuming an **isotropic probability of the kick direction**.

- Blaauw kick (spherically symmetric mass loss, Blaauw 1961)
- Asymmetric kick (random direction)



Hypotheses:

- circularized systems (initial mass transfer)
- fixed NS mass @ $1.4M_{Sun}$
- companion is unaffected by the supernova

We can infer kick only for HMXBs with an orbital period: the final sample is **35 HMXBs.**

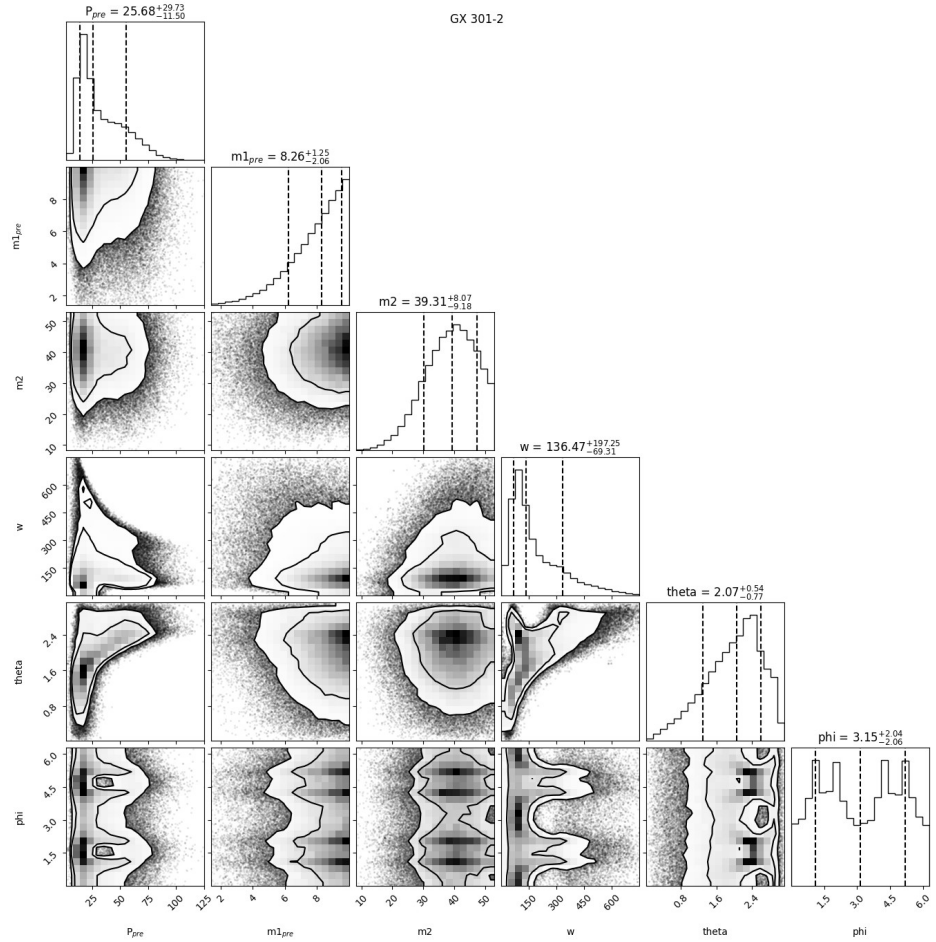
Deriving kicks

Bayesian approach:

- Priors on kick magnitude, initial P_{orb} and pre-SN mass

- Likelyhoods: Gaia observables, companion mass, P_{orb} & eccentricity

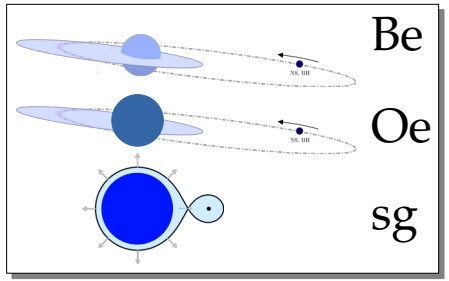
→ Explore the posterior distributions using Markov Chain Monte Carlo (MCMC) scheme



Inferring kick distributions on HMXB subtypes

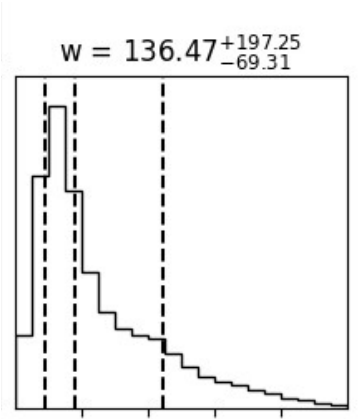
We have a posterior probability of kick velocities for each 35 HMXBs.

→ How can we characterize the kick distributions on each HMXB subtypes ?



To get a representative distribution, we use a bootstrap method:

- for each HMXB, draw a random kick velocity according to its posterior probability
- 1 bootstrap iteration is a collection of those random draws, is effectively one possible posterior for the whole HMXB subtype population
- iterate 1000 times
- get a collection of possible kick posteriors for a subtype



→ Fit each posteriors with an appropriate function, retrieve median parameters.

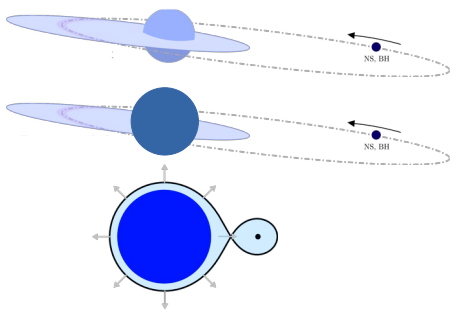
Results on kick distributions

Inferred kick magnitudes on 35 HMXB :

17 Be

8 Oe

10 Sg



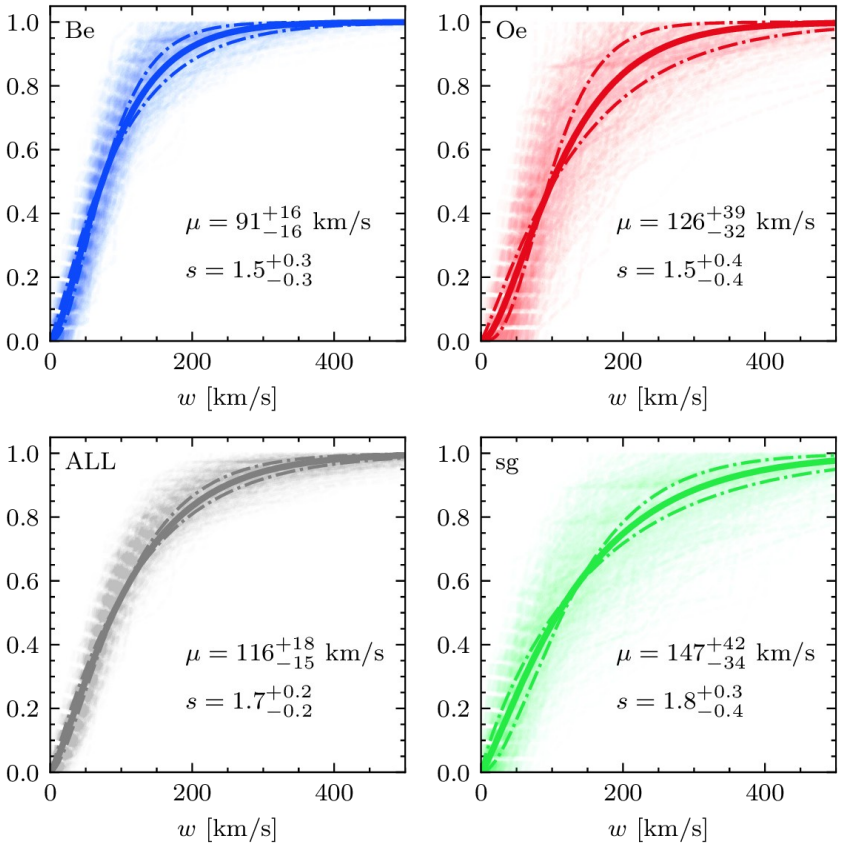
→ Kicks are reproduced with Gamma functions

(instead of the commonly used Maxwellian)

→ Can be confronted to population synthesis models

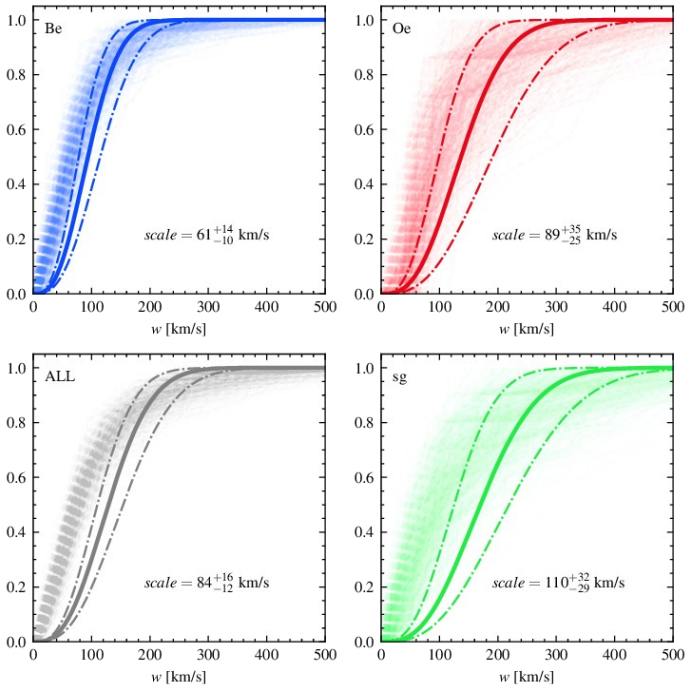
in order to constrain the physics behind

Cumulative distributions of kicks

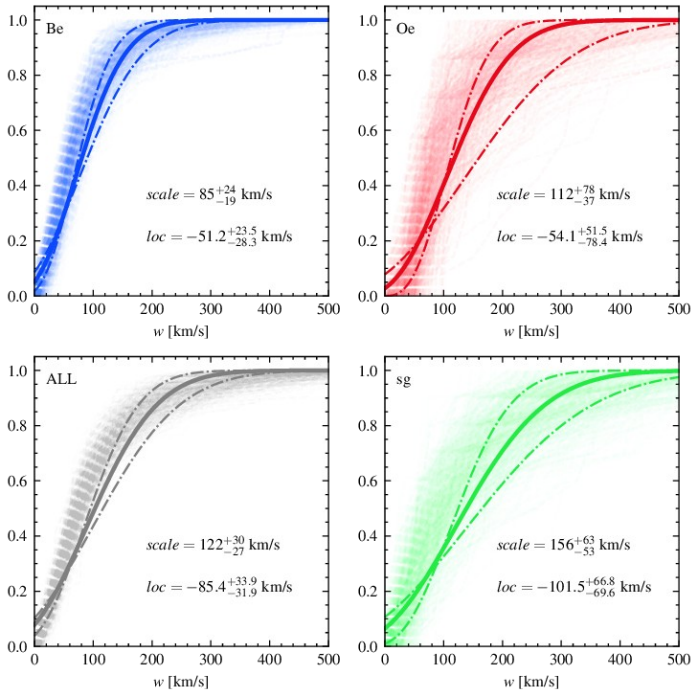


Discussion: Maxwellian vs. Gamma

Maxwellian is historically used to model kicks in isolated pulsars (Hobbs+2005, Ng & Romani 2007, Noutsos+2013)



Classical Maxwellian



Shifted Maxwellian

Unbound systems ?

→ observed vs. pop synth.

Stripped progenitors ?

→ lower pre-SN mass

Kick isotropy ?

→ NS spin axis

Prospects: HMXB birthplace, Gaia DR3, catalogue

Finding the birthplace of HMXBs in the Galaxy

→ We have the peculiar velocity of HMXBs

→ If they are born within clusters, we could find them in Gaia → get their peculiar velocity

→ Integrate orbits over ~Myr to find candidate birthplaces for Galactic HMXBs.

Upcoming release(s) of Gaia

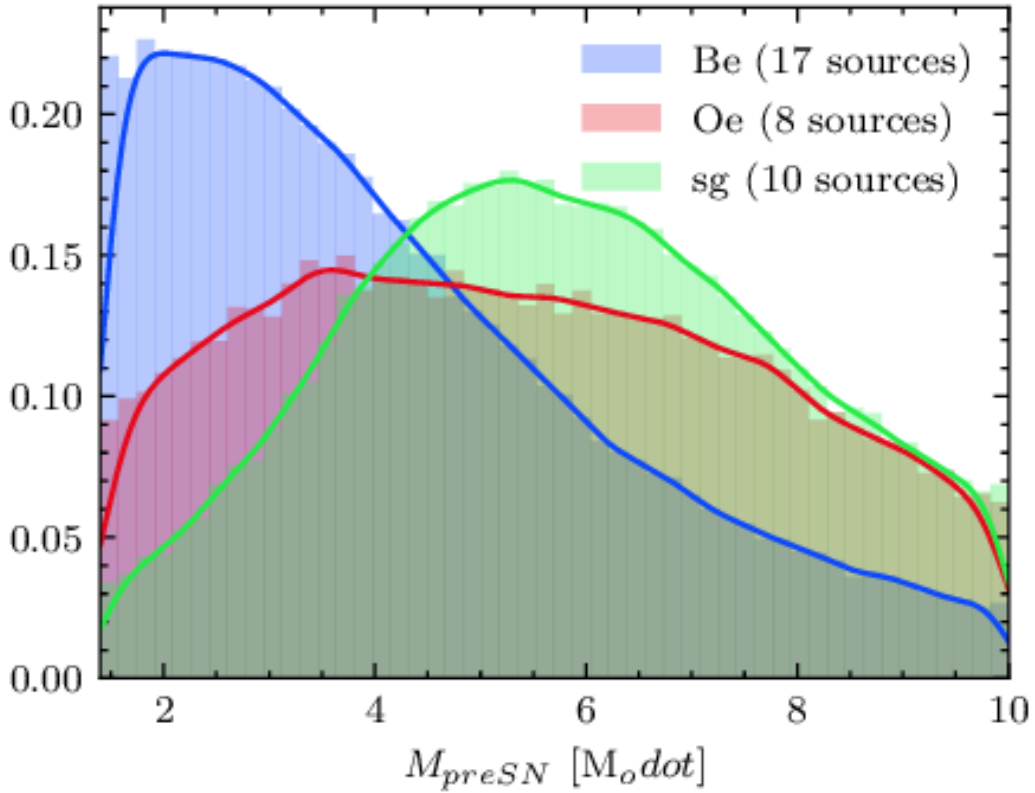
→ Gaia DR3 improvement over EDR3: addition of astrophysical parameters & some RVs

→ No additional source, no improvement on astrometry

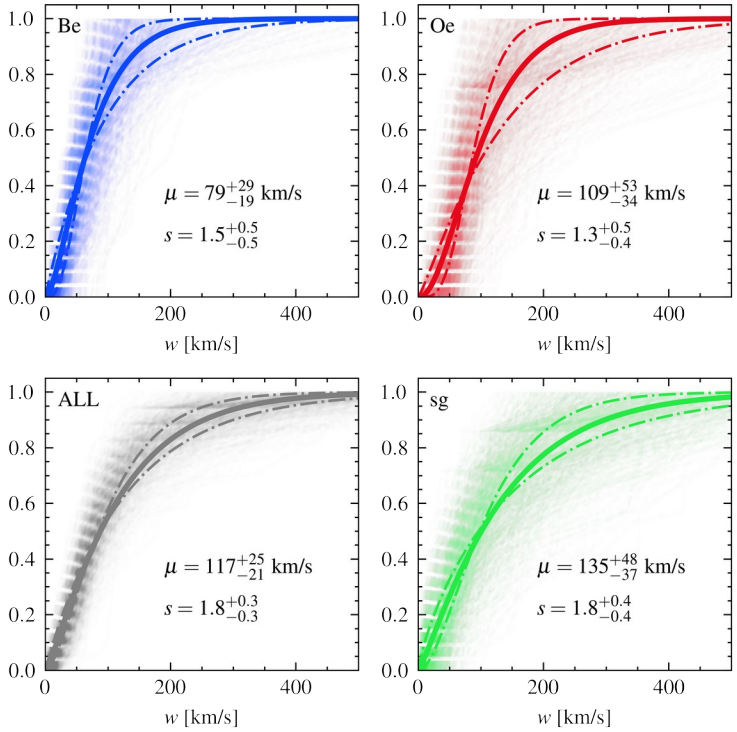
→ Full release TBD, extra sources with more constrained astrometry.

Catalogue of High-Mass X-ray Binaries in the Milky Way

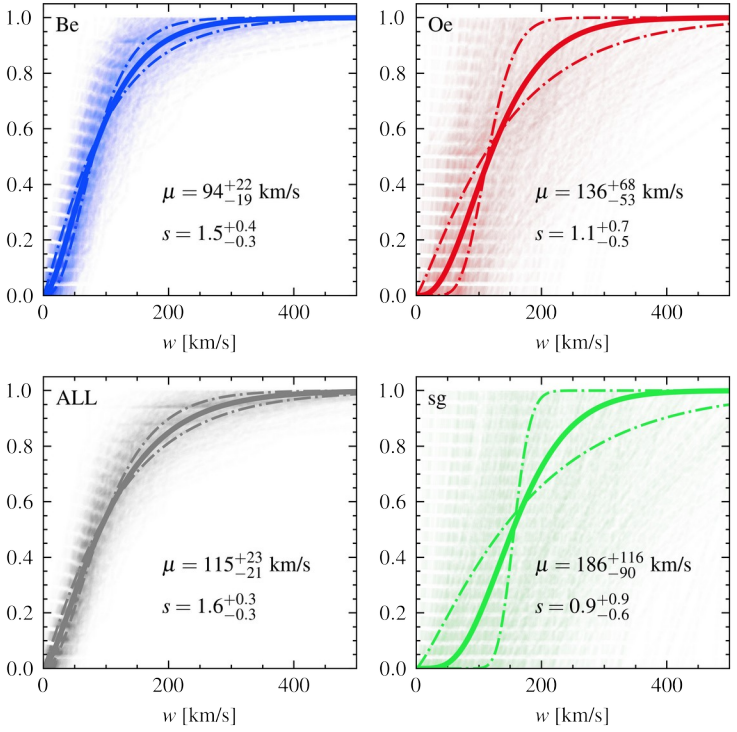
Extra: $M_{pre\text{-}SN}$ distribution



Extra: impact of missing radial velocity



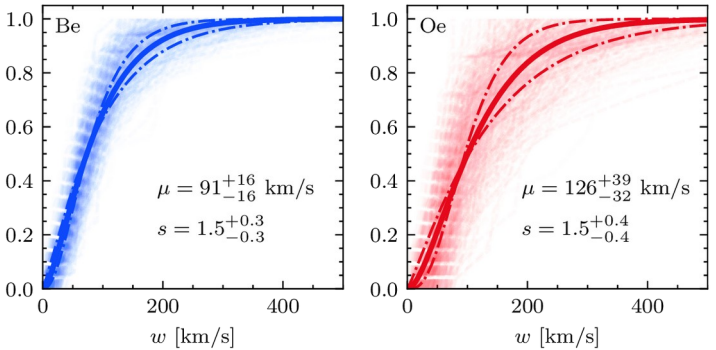
With RV only



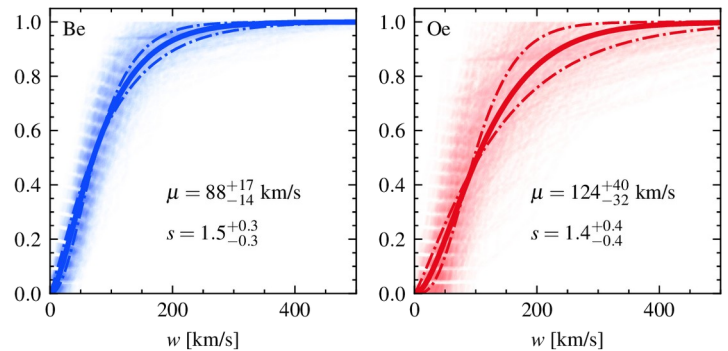
Without RV only

Extra: impact of neutron star mass

→ Assumed constant NS mass of 1.4 Msun, what about more massive NSs ?



$M_{NS} = 1.4\ M_{Sun}$



$M_{NS} = 1.8\ M_{Sun}$

No notable difference on the fitted parameters

→ NS mass variation are much smaller than $M_{pre\text{-}SN}$ uncertainty